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METHOD AND APPARATUS FOR THREE DIMENSIONAL INSPECTION OF ELECTRONIC COMPONENTS

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a continuation-in-part of pending

5 U.S. Application No. 09/008,243 filed 1/16/98, entitled

METHOD AND APPARATUS FOR THREE DIMENSIONAL INSPECTION OF

ELECTRONIC COMPONENTS, incorporated by reference herein.

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FIELD OF THE INVENTION

This invention relates to a method and apparatus for

three dimensional inspection and, more particularly, a

method and apparatus for three dimensional inspection of

20 solder balls on ball grid arrays and solder bumps on wafer

and die, and to a calibration method.

BACKGROUND OF THE INVENTION

Prior art three dimensional inspection systems have

involved laser range finding technology, moiré

25 interferometry, structured light patterns or two cameras.

The laser range finding method directs a focused laser beam onto the Ball Grid Array, BGA, and detects the reflected beam with a sensor. Elements of the BGA are determined in the X, Y and Z dimensions utilizing a triangulation method.

5 This method requires a large number of measurement samples to determine the dimensions of the BGA resulting in longer inspection times. This method also suffers from specular reflections from the smooth surfaces of the solder balls resulting in erroneous data.

10· Moiré interferometry utilizes the interference of light waves generated by a diffraction grating to produce a pattern of dark contours on the surface of the BGA. These contours are of known distance in the Z dimension from the diffraction grating. By counting the number of contours

15 from one point on the BGA to another point on the BGA, the distance in the Z dimension between the two points can be determined. This method suffers from the problem of low contrast contour lines resulting in missed counting of the number of contours and resulting in erroneous data. This

20 method also suffers from the contour lines merging at surfaces with steep slopes, such as the sides of the balls on the BGA, resulting in an incorrect count of the number of contours and resulting in erroneous data.

Structured light systems project precise bands of light

25 onto the part to be inspected. The deviation of the light band from a straight line is proportional to the distance

from a reference surface. The light bands are moved across the part, or alternately the part is moved with respect to the light bands, and successive images are acquired. The maximum deviation of the light band indicates the maximum

5   height of a ball. This method suffers from specular reflections due to the highly focused nature of the light bands resulting in erroneous data. This method further suffers from increased inspection times due to the number of images required.

10   Two camera systems utilize one camera to view the BGA device in the normal direction to determine X and Y dimensions and the second camera to view the far edges of the balls from an angle. The two images are combined to determine the apparent height of each ball in the Z

15   dimension utilizing a triangulation method. This method suffers from the need for a higher angle of view of the ball from the second camera resulting in looking at a point significantly below the top of the ball for BGA's having fine pitch. This method also suffers from limited depth of

20   focus for the second camera limiting the size of BGA's that can be inspected. This system can only inspect BGA's and not other device types such as gullwing and J lead devices.

The prior art does not provide two separate and opposite side views permitting larger BGA's to be inspected

25   or nonlinear optics to enhance the separation between adjacent ball images in the side perspective view.

It is therefore a motivation of the invention to improve the accuracy of the measurements, the speed of the measurements, the ability to measure all sizes and pitches of BGA's and to measure other devices including gullwing and

5 J lead parts in a single system.

SUMMARY OF THE INVENTION

The invention provides an apparatus for three dimensional inspection of an electronic part, wherein the apparatus is calibrated using a precision pattern mask with

10 dot patterns deposited on a calibration transparent reticle, the apparatus for three dimensional inspection of an electronic part comprising a camera and an illuminator for imaging the electronic part, the camera being positioned to obtain a first view of the electronic part, a means for

15 light reflection positioned to reflect a different view of the electronic part into the camera, wherein the camera provides an image of the electronic part having differing views of the electronic part, and a means for image processing the image of the electronic part that applies

20 calculations on the differing views of the image to calculate a three dimensional position of at least one portion of the electronic part.

The invention further comprises a ring light. The means for light reflection could further comprise a mirror, a

25 prism, or a curved mirror. The electronic part may be a ball grid array, balls on a wafer, or balls on a die.

The means for imaging provides the image to a frame grabber board. The frame grabber board provides an image data output to a processor to perform a three dimensional inspection of the part.

5   The apparatus may further comprise a nonlinear optical element to magnify the second image in one dimension. In the apparatus a maximum depth of focus of a side perspective view allows for a fixed focus system to inspect larger electronic parts, with one perspective view imaging one

10   portion of the electronic part and a second perspective view imaging a second portion of the electronic part. Also, in the apparatus a maximum depth of focus of a side perspective view includes an area of the electronic part including a center row of balls. Furthermore, all of the balls on the

15   electronic part may be in focus resulting in two perspective views for each ball.

The invention comprises a means for inspecting gullwing and J lead devices.

The invention further provides a method for three

20   dimensional inspection of a lead on a part, the method comprising the steps of using a camera to receive an image of the lead, transmitting the image of the lead to a frame grabber, providing fixed optical elements to obtain a side perspective view of the lead, transmitting the side

25   perspective view of the lead to the frame grabber, operating a processor to send a command to the frame grabber to

acquire images of pixel values from the camera, and processing the pixel values with the processor to calculate a three dimensional position of the lead. State values may be determined from the part itself.

5   The lead may be a curved surface lead, a ball, a ball grid array, a formed wire, a stamped metal form or similar object that can be imaged from two separate directions.

The processor processes the pixel values to find a rotation, an X placement value and a Y placement value of 10   the part relative to world X and Y coordinates by finding points on four sides of the part.

The invention further provides the steps of using a part definition file that contains measurement values for an ideal part, calculating an expected position for each lead 15   of the part for a bottom view using the measurement values from the part definition file and the X placement value and Y placement value.

The invention further provides the step of using a search procedure on the image data to locate the lead.

20   The invention further provides the step of determining a lead center location and a lead diameter in pixels and storing the lead center location and lead diameter in memory.

The invention further provides the step of calculating 25   an expected position of a center of each lead in both side perspective views in the image using a known position of

each side view from calibration.

The invention further provides the step of using a subpixel edge detection method to locate a reference point on each lead.

5   The invention further provides the step of converting the pixel values into world locations by using pixel values and parameters determined during calibration wherein the world locations represent physical locations of the lead with respect to world coordinates defined during

10   calibration.

The invention further provides for the calculation of a Z height of each lead in world coordinates in pixel values by combining a location of a center of a lead from a bottom view with a reference point of the same lead from a side

15   perspective view.

The invention further provides the step of converting the world values to part values using the rotation, the X placement value and the Y placement value to define part coordinates for the ideal part where the part values

20   represent physical dimensions of the lead including lead diameter, lead center location in X part and Y part coordinates and lead height in Z world coordinates.

The invention further provides the step of comparing ideal values defined in the part file to calculate deviation

25   values that represent a deviation of the center of the lead from its ideal location. The deviation values may include

lead diameter in several orientations with respect to the X

placement value and Y placement value, lead center in the X

direction, Y direction and radial direction, lead pitch in

the X direction and Y direction and missing and deformed

5   leads, further comprising the step of calculating the Z

dimension of the lead with respect to the seating plane

based on the Z world data.

The invention further provides the step of comparing

the deviation values to predetermined tolerance values with

10   respect to an ideal part as defined in the part definition

file to provide a lead inspection result.

BRIEF DESCRIPTION OF THE DRAWINGS

To illustrate this invention, a preferred embodiment

will be described herein with reference to the accompanying

15   drawings.

Figure 1A shows the apparatus of the invention for

system calibration.

Figure 1B shows an example calibration pattern and

example images of the calibration pattern acquired by the

20   system.

Figure 2A shows a flow chart of a method of the

invention used for calibration of the bottom view.

Figure 2B shows a flow chart of a method of the

invention used for determining the state values, and the X

25   and Y world coordinates, of the bottom view of the system.

Figure 2C shows a flow chart of a method of the

invention used for calibration of the side perspective views.

Figure 2D shows a flow chart of a method of the invention used for determining the state values of the side perspective views of the system.

Figure 2E shows the relationship of a side perspective angle to the ratio of the perspective dimensions to the non-perspective dimensions.

Figure 2F shows a bottom view and a side perspective view of precision dots used in the method for determining a side perspective view angle.

Figure 3A shows the apparatus of the invention for part inspection.

Figure 3B shows example images of a part acquired by the system.

Figure 4 shows a method of the invention for the three dimensional inspection of balls on a ball grid array.

Figures 5A and 5B together show a flow chart of the three dimensional inspection method of the invention.

Figures 6A and 6B show an example ball of a ball grid array and associated geometry used in a method of the invention for determining the Z position of the ball.

Figure 7A shows one example of an image used in the grayscale blob method of the invention.

Figure 7B shows one example of an image used with the method of the invention to perform a subpixel measurement of

the ball reference point.

Figure 8A shows a side perspective image of the calibration pattern magnified in one dimension.

Figure 8B shows a side perspective image of the balls
5   on a BGA, magnified in one dimension.

Figure 9 shows an apparatus for presenting a BGA for inspection.

Figures 10A and 10B show an example ball of a ball grid array with associated geometry as used with a method of the
10   invention for determining the Z position of a ball using two side perspective views.

Figure 11A shows the apparatus of the invention for system calibration, utilizing a single side perspective view.

15   Figure 11B shows an example calibration pattern and example images of a calibration pattern acquired by the system, utilizing a single side perspective view, of the invention.

Figure 12A shows the apparatus of the invention for
20   ball inspection utilizing a single side perspective view.

Figure 12B shows an example ball grid array and example images of the ball grid array for three dimensional inspection, utilizing a single side perspective view.

Figure 13 shows the apparatus of the invention for the
25   three dimensional inspection of ball grid array devices, gullwing devices and J lead devices.

Figure 14 shows the apparatus of the invention for the three dimensional inspection of parts utilizing three cameras.

Figure 15 shows the apparatus of the invention
5   configured with a calibration reticle 1020 for use during calibration of the state values of the system.

Figures 16A and 16B show an example calibration pattern and example images of the calibration pattern acquired by the single camera system.

10   Figure 17 shows the apparatus of the invention configured with a part 1040 to be inspected by the system.

Figures 18A and 18B show a part and example images of a part acquired by the system.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

15   In one embodiment of the invention, the method and apparatus disclosed herein is a method and apparatus for calibrating the system by placing a pattern of calibration dots of known spacing and size on the bottom plane of a calibration reticle. From the precision dots the missing
20   state values of the system are determined allowing for three dimensional inspection of balls on ball grid array devices, BGA devices or balls on wafers or balls on die. In one embodiment of the invention the system may also inspect gullwing and J lead devices as well as ball grid arrays.

25   Refer now to Figure 1A which shows the apparatus of the invention configured with a calibration reticle for use

during calibration of the state values of the system. The
apparatus obtains what is known as a bottom image 50 of the
calibration reticle 20. To take the bottom image 50 the
apparatus includes a camera 10 with a lens 11 and

5   calibration reticle 20 with a calibration pattern 22 on the
bottom surface. The calibration pattern 22 on the reticle
20 comprises precision dots 24. The camera 10 is located
below the central part of the calibration reticle 20 to
receive an image 50 described in conjunction with Figure 1B.

10   In one embodiment the camera 10 comprises an image sensor.
The image sensor may be a charged coupled device array. The
camera 10 is connected to a frame grabber board 12 to
receive the image 50. The frame grabber board 12 provides
an image data output to a processor 13 to perform a two

15   dimensional calibration as described in conjunction with
Figure 2A. The processor 13 may store an image in memory
14. The apparatus of the invention obtains an image of a
pair of side perspective views and includes using a camera
15 with a lens 16 and a calibration reticle 20. The camera

20   15 is located to receive an image 60, comprising a pair of
side perspective views, described in conjunction with Figure
1B. Fixed optical elements 30, 32 and 38 provide a first
side perspective view and fixed optical elements 34, 36, 38
for a second side perspective view. The fixed optical

25   elements 30, 32, 34, 36 and 38 may be mirrors or prisms. As
will be appreciated by those skilled in the art additional

13

optical elements may be incorporated. The camera 15 is
connected to a frame grabber board 17 to receive the image
60. The frame grabber board 17 provides an image data
output to a processor 13 to perform a two dimensional

5   inspection as described in conjunction with Figure 2B. The
processor 13 may store an image in memory 14. In one
embodiment of the invention, the apparatus may contain a
nonlinear optical element 39 to magnify the side perspective
image 60 in one dimension as shown in Figure 8A. In another

10   embodiment of the invention optical element 38 may be a
nonlinear element. The nonlinear optical elements 38 and 39
may be a curved mirror or a lens.

Figure 1B shows an example image 50 from camera 10 and
an example image 60 from camera 15 acquired by the system.

15   The image 50, a bottom view of dot pattern 22, shows dots 52
acquired by camera 10. The dot pattern contains precision
dots 24 of known dimensions and spacing. The precision dots
24 are located on the bottom surface of the calibration
reticle 20. The image 60 shows two side perspective views

20   of the dot pattern 22. A first side perspective view in
image 60 contains images 62 of dots 24 and is obtained by
the reflection of the image of the calibration reticle dot
pattern 22 off of fixed optical elements 30, 32 and 38 into
camera 15. A second side perspective view in image 60

25   contains images 66 of dots 24 and is obtained by the
reflection of the image of the calibration reticle dot

pattern 22 off of fixed optical elements 34, 36 and 38 into camera 15.

Optical element 36 is positioned to adjust the optical path length of a second side perspective view to equal the optical path length of a first side perspective view. Those skilled in the art will realize that any number of perspective views can be utilized by the invention. In one embodiment of the invention, the maximum depth of focus of a side perspective view includes an area of the reticle including the center row of dots. This allows for a fixed focus system to inspect larger parts, with one perspective view imaging half of the part and the second perspective view imaging the other half of the part.

Figure 2A shows a flow diagram for the calibration of the bottom view of the system. The method starts in step 101 by providing a transparent reticle 20 having a bottom surface containing a dot pattern 22, comprising precision dots 24 of known dimensions and spacing. The method in step 102 provides a camera 10 located beneath the transparent reticle 20 to receive an image 50. In step 103 the processor 13 sends a command to a frame grabber 12 to acquire an image 50, comprising pixel values from the camera 10. The method then proceeds to step 104 and processes the pixel values with a processor 13.

Figure 2B shows a flow diagram for determining the state values of the bottom view of the system. In step 111

the method begins by finding the dots 52 in image 50,

corresponding to the calibration dots 24. The processor

finds a dimension and position for each dot visible in image

50 in subpixel values using well known grayscale methods and

5   stores these values in memory 14. By comparing these

results to known values stored in memory, the processor

calculates the missing state values for the bottom

calibration in steps 112 and 113. In step 112 the processor

13 calculates the optical distortion of lens 11 and the

10   camera roll angle with respect to the dot pattern 22. Step

113 calculates the pixel width and pixel height by comparing

the subpixel data of dots 52 with the known dimensions of

the precision dot pattern 22. The pixel aspect ratio is

determined from the pixel width and pixel height. In step

15   114 the processor defines the X and Y world coordinates and

the Z=0 plane from the image 50 of the precision dot pattern

22. The processor then stores these results in memory.

These results provide conversion factors for use during

analysis to convert pixel values to world values.

20   Figure 2C shows a flow diagram for the calibration of

the side perspective views of the system. The method starts

in step 121 by providing a transparent reticle 20 having a

bottom surface containing a dot pattern 22, comprising

precision dots 24 of known dimensions and spacing. The

25   method in step 122 provides fixed optical elements 30, 32,

34, 36 and 38 to reflect two perspective images of the

precision dot pattern 22 into camera 15. The method in step 123 provides a camera 15 located to receive an image 60. In step 124 the processor 13 sends a command to a frame grabber 12 to acquire an image 60, comprising pixel values from the

5   camera 15. The method then proceeds to step 125 and processes the pixel values with a processor 13.

Figure 2D shows a flow diagram for determining the state values of the side perspective views of the system. In step 131 the method begins by finding dots 62 in image

10   60, corresponding to the calibration dots 24. The processor finds a dimension and position for each dot visible, comprising the group of dots 62, in image 60 for a first side perspective view in subpixel values and stores these values in memory 14. By comparing these results to known

15   values stored in memory, the processor calculates the missing state values for a side perspective view, comprising the group of dots 62, in steps 132 and 133. In step 132 the processor 13 calculates the optical distortion of lens 16 and the camera roll angle with respect to the dot pattern

20   22. In step 133 the processor 13 calculates the pixel width and pixel height by comparing the subpixel data of dots 62 with the known dimensions of the precision dots 24. The pixel aspect ratio is determined from the pixel width and pixel height. In step 134 the processor defines the X and Y

25   world coordinates and the Z=0 plane from the dots 62 in image 60 of the dot pattern 22. The processor then stores

these results in memory. These results provide conversion factors for use during analysis to convert pixel values to world values. In step 135 the method of the invention computes the side view angle. In step 136 the method is

5   repeated for a second side perspective view using the dots 66 in image 60.

Figure 2E shows the relationship of a side perspective angle to the ratio of the perspective dimension to the non-perspective dimension. Ray 171, 172, and 173 defining point

10   181 is parallel to ray 174, 175 and 176 defining point 182. Point 181 and point 182 lie on a plane 170 parallel to a plane 180. The intersection of ray 175 and ray 176 define point 186. The intersection of ray 176 and ray 172 define point 184. The intersection of ray 173 and ray 172 define

15   point 187. The intersection of ray 174 and ray 172 define point 183. The reflecting plane 179 intersecting plane 180 at an angle D is defined by ray 172 and ray 175 and the law of reflectance. Ray 172 and ray 175 intersect plane 170 at an angle 177. Referring to Figure 2E it can be shown:

$$\tan\theta = \frac{C}{D_B}$$

$$\frac{C}{\sin A} = \frac{L}{\sin A} \quad \textit{Therefore: } C = L$$

$$\cos\theta = \frac{D_S}{L} = \frac{D_S}{C}$$

$$C = \frac{D_S}{\cos\theta}$$

Substituting:

$$\tan\theta = \frac{\dfrac{D_S}{\cos\theta}}{D_B} = \frac{D_S}{D_B\cos\theta}$$

$$(\tan\theta)(\cos\theta) = \frac{D_S}{D_B} = \sin\theta$$

$$\theta = \arcsin\left(\frac{D_S}{D_B}\right)$$

Figure 2F shows a bottom view and a side perspective view of precision dots used in the method for determining a side perspective view angle 177 as shown in Figure 2E of the system. A bottom view image 200 comprising precision dots 201, 202 and 203 of known spacing and dimensions from the calibration method described earlier can be used to provide a reference for determination of a side perspective view angle 177. The value D_H and D_B are known from the bottom view calibration. A side perspective view image 210 comprising precision dots 211, 212 and 213, corresponding to

bottom view dots 201, 202 and 203 respectively, of known

spacing and dimensions D_S and D_h from the calibration method

described earlier, can be used to determine the side view

perspective angle. The ratio of $(D_h \ / \ D_H)$ from the bottom

5   image 200 and the side perspective image 210 can be used in

the bottom view to calibrate D_B in the same units as the

side perspective view as follows:

$$D_{Bcal} = D_B (D_h/D_H)$$

Substituting into the equation for the side perspective view

10   angle 177 described earlier yields:

$$\theta = \arcsin\left(\frac{D_S}{D_B}\right) = \arcsin\left(\frac{D_S}{D_{Bcal}}\right)$$

$$\theta = \arcsin\left(\frac{D_S D_H}{D_B D_h}\right)$$

Figure 3A shows the apparatus of the invention for a

three dimensional inspection of the balls of a ball grid

array. The apparatus of the invention includes a part 70 to

be inspected. The apparatus further includes a camera 10

15   with a lens 11, located below the central area of part 70,

to receive a bottom image 80, described in conjunction with

Figure 3B, of part 70. The camera 10 is connected to a

frame grabber board 12 to receive the image 80. The frame

grabber board 12 provides an image data output to a

20   processor 13 to perform a two dimensional inspection as

described in conjunction with Figure 3A. The processor 13

may store an image in memory 14. The apparatus of the

invention obtains an image of a pair of side perspective views with a camera 15 and a lens 16. The camera 15 is located to receive an image 90, comprising a pair of side perspective views, described in conjunction with Figure 3B

5 and utilizing fixed optical elements 30, 32 and 38 for a first side perspective view and fixed optical elements 34, 36 and 38 for a second side perspective view. In one embodiment of the invention, the apparatus may contain a nonlinear optical element 39 to magnify the side perspective

10 image 60 in one dimension as shown in Figure 8B. In another embodiment of the invention optical element 38 may be the nonlinear element. The fixed optical elements 30, 32, 34, 36 and 38 may be mirrors or prisms. As will be appreciated by those skilled in the art additional optical elements may

15 be incorporated without deviating from the spirit and scope of the invention. The camera 15 is connected to a frame grabber board 17 to receive the image 90. The frame grabber board 17 provides an image data output to a processor 13 to calculate the Z position of the balls, described in

20 conjunction with Figure 3B. The processor 13 may store an image in memory 14.

Figure 3B shows an example image 80 from camera 10 and an example image 90 from camera 15 acquired by the system. The image 80 shows the bottom view of the balls located on

25 the bottom surface of a part 70. The image 90 shows two side view perspectives of the balls located on part 70. A

first side perspective view in image 90 contains images of balls 91 and is obtained by the reflection of the image of the part 70 off of fixed optical elements 30, 32 and 38 into camera 15. A second side perspective view in image 90

5 contains images of balls 92 and is obtained by the reflection of the image of the part 70 off of fixed optical elements 34, 36 and 38 into camera 15. Optical element 36 is positioned to adjust the optical path length of a second side perspective view to equal the optical path length of a

10 first side perspective view. In one embodiment of the invention, the maximum depth of focus of a side perspective view just includes an area of the part including the center row of balls. This allows for a fixed focus system to inspect larger parts, with one perspective view imaging at

15 least half of the part and the second perspective view imaging at least the other half of the part. Those skilled in the art will realize that any number of perspective views can be utilized by the invention. In another embodiment of the invention, all of the balls are in focus from both side

20 perspective views resulting in two perspective views for each ball. This permits two Z calculations for each ball as shown in conjunction with Figures 10A and 10B.

Figure 4 shows a flow diagram for the three dimensional inspection of balls on a ball grid array. The method starts

25 in step 141 by providing a part 70 having balls 71 facing down. The method in step 142 provides a camera 10 located

beneath the part 70 to receive an image 80. In step 143 a frame grabber12 is provided to receive the image 80 from camera 10. In step 144, fixed optical elements are provided for obtaining two side perspective views of the part 70. A

5 first optical path is provided by optical elements 30, 32 and 38. A second optical path is provided by optical elements 34, 36 and 38. A second camera 15 receives an image 90 of two side perspective views in step 145. In step 146 a second frame grabber board 17 is provided to receive

10 the image 90 from camera 15. A processor 13 sends a command to frame grabbers 12 and 17 to acquire images 80 and 90 comprising pixel values from cameras 10 and 15. The method then proceeds to step 147 and processes the pixel values with a processor 13 to obtain three dimensional data about

15 part 70.

The invention contemplates the inspection of parts that have ball shaped leads whether or not packaged as a ball grid array. The invention also contemplates inspection of leads that present a generally curvilinear profile to an

20 image sensor.

Figures 5A and 5B together show a flow chart of the three dimensional inspection method of the invention. The process begins in step 151 by waiting for an inspection signal. When the signal changes state, the system initiates

25 the inspection. The processor 13 sends a command to frame grabber boards 12 and 17 to acquire images 80 and 90

respectively of part 70 having balls 71. In step 152,

camera 10 captures an image 80 comprising pixel values and

camera 15 captures an image 90 comprising pixel values and

the processor stores the images in memory 14. The images

5   comprise information from both a bottom view and two side

perspective views as shown in Figure 3B. In step 153, the

inspection system sends a signal to a part handler shown in

Figure 9 to allow the part handler to move the part out of

the inspection area and allows the next part to be moved

10   into the inspection area. The handler may proceed with part

placement while the inspection system processes the stored

image data.

The inspection system processes the pixel values of the

stored image 80 in step 154 to find a rotation, and X

15   placement and Y placement of the part relative to the world

X and Y coordinates. The processor determines these

placement values finding points on four sides of the body of

the part. In step 155, the processor employs a part

definition file that contains values for an ideal part.

20   By using the measurement values from the part

definition file and the placement values determined in step

154, the processor calculates an expected position for each

ball of the part for the bottom view contained in image 80.

The processor employs a search procedure on the image data

25   to locate the balls 81 in image 80. The processor then

determines each ball's center location and diameter in pixel

values using grayscale blob techniques as described in Figure 7A. The results are stored in memory 14.

The processor proceeds in step 156 to calculate an expected position of the center of each ball in both side perspective views in image 90 using the known position of each side view from calibration. The processor employs a subpixel edge detection method described in Figure 7B to locate a reference point on each ball in step 157. The results are stored in memory 14.

Now refer to Figure 5B. In step 158 the processor converts the stored pixel values from steps 154 and 157 into world locations by using pixel values and parameters determined during calibration. The world locations represent physical locations of the balls with respect to the world coordinates defined during calibration.

In step 159 the Z height of each ball is calculated in world coordinates in pixel values. The method proceeds by combining the location of the center of a ball from the bottom view 80 with the reference point of the same ball from a side perspective view in image 90 as described in Figures 6A and 6B. The processor then converts the world values to part values using the calculated part rotation, and X placement and Y placement in step 160 to define part coordinates for the ideal part. The part values represent physical dimensions of the balls such as ball diameter, ball center location in X part and Y part coordinates and ball

height in Z world coordinates.

In step 161 these part values are compared to the ideal values defined in the part file to calculate the deviation of each ball center from its ideal location. In one example embodiment of the invention the deviation values may include ball diameter in several orientations with respect to the X and Y part coordinates, ball center in the X direction, Y direction and radial direction, ball pitch in the X direction and Y direction and missing and deformed balls. The Z world data can be used to define a seating plane, using well known mathematical formulas, from which the Z dimension of the balls with respect to the seating plane can be calculated. Those skilled in the art will recognize that there are several possible definitions for seating planes from the data that may be used without deviating from the spirit and scope of the invention.

In step 162 the results of step 161 are compared to predetermined thresholds with respect to the ideal part as defined in the part file to provide an electronic ball inspection result. In one embodiment the predetermined tolerance values include pass tolerance values and fail tolerance values from industry standards. If the measurement values are less than or equal to the pass tolerance values, the processor assigns a pass result for the part. If the measurement values exceed the fail tolerance values, the processor assigns a fail result for

the part. If the measurement values are greater than the

pass tolerance values, but less than or not equal to the

fail tolerance values, the processor designates the part to

be reworked. The processor reports the inspection result

5   for the part in step 163, completing part inspection. The

process then returns to step 151 to await the next

inspection signal.

Figures 6A and 6B show an example ball of a ball grid

array and associated geometry used in a method of the

10   invention for determining the Z position of the ball. The

method determines the Z position of a ball with respect to

the world coordinates defined during calibration. Using

parameters determined from the calibration procedure as

shown in Figures 2B and 2D to define a world coordinate

15   system for the bottom view and the two side perspective

views, comprising world coordinate plane 250 with world

coordinate origin 251 and world coordinate axis X 252, Y 253

and Z 254 shown in Figure 6A, and a pair of images 80 and 90

as shown in Figure 3B, the processor computes a three

20   dimensional location.

Now refer to Figure 6A. The processor locates a point

258 on the world plane 250 determined by a bottom view ray

255 passing through the center 257 of a ball 71 on a part

70. The processor locates a side perspective view point 260

25   on the world plane 250 determined by a side perspective view

ray 256 intersecting a ball reference point 259 on ball 71

and intersecting the bottom view ray 255 at a virtual point 261. Ray 256 intersects the world plane 250 at an angle 262 determined by the reflection of ray 256 off of the back surface 263 of prism 30. The value of angle 262 was

5   determined during the calibration procedure.

Now refer to Figure 6B. The distance L_1 is calculated by the processor as the difference between world point 258, defined by the intersection of ray 255 with the Z=0 world plane 250, and world point 260, defined by the intersection

10   of ray 256 and the Z=0 world plane 250. The value Z is defined as the distance between world point 261 and 258 and is related to L_1 as follows:

$$\tan\theta_1 = \frac{Z}{L_1}$$

$$Z = L_1\tan\theta_1$$

Z can be computed by processor 13 since the angle 262 is known from calibration. The offset E 265 is the

15   difference between the virtual point 261 defined by the intersection of ray 255 and ray 256 and the crown of ball 71 at point 264, defined by the intersection of ray 255 with the crown of ball 71, and can be calculated from the knowledge of the angle 262 and the ideal dimensions of the

20   ball 71. The final value of Z for ball 71 is:

$$Z_{Final} = Z - E$$

Figure 7A shows one example of an image used in the grayscale blob method of the invention. The image

processing method finds the location and dimensions of a

ball 71 from a bottom image 80. From the expected position

of a ball 71, a region of interest in image 80 is defined as

(X1, Y1) by (X2,Y2). The width and height of the region of

5   interest are large enough to allow for positioning

tolerances of part 70 for inspection. Due to the design of

the lighting for the bottom view, the spherical shape of

balls 71 of part 70 present a donut shaped image where the

region 281, including the perimeter of the ball 71,

10   comprises camera pixels of higher grayscale values and where

the central region 282 comprises camera pixels of lower

grayscale values. The remainder 283 of the region of

interest 280 comprises camera pixels of lower grayscale

values.

15   In one embodiment of the invention the processor 13

implements image processing functions written in the C

programming language.

The C language function "FindBlobCenter", as described

below, is called to find the approximate center of the ball

20   71 by finding the average position of pixels that are

greater than a known threshold value. Using the coordinates

of the approximate center of the ball 71, the region 282 of

lower grayscale pixel values can be converted to higher

grayscale values by calling the C language function

25   "FillBallCenter", as described below. The exact center of

the ball 71 can be found by calling the C language function

"FindBallCenter" which also returns an X world and Y world coordinate. The diameter of the ball 71 can be calculated by the C language function, "Radius=sqrt(Area/3.14)". The area used in the diameter calculation comprises the sum of

5 pixels in region 281 and 282.

Figure 7B shows one example of an image used with the method of the invention to perform a subpixel measurement of the ball reference point. The method of the invention finds a reference point on a ball 71 in an image 90 of a side

10 perspective view as shown in Figure 3B. From the expected position of a ball 71, a region of interest 290 in image 80 is defined as (X3, Y3) by (X4,Y4). The width and height of the region of interest are large enough to allow for positioning tolerances of part 70 for inspection. Due to

15 the design of the lighting for a side perspective view, the spherical shape of balls 71 of part 70 present a crescent shaped image 291 comprising camera pixels of higher grayscale values and where the remainder 293 of the region of interest 290 comprises camera pixels of lower grayscale

20 values.

The C language function "FindBlobCenter" is called to compute the approximate center of the crescent image 291 by finding the average position of pixels that are greater than a known threshold value. Using the coordinates of the

25 approximate center of the crescent image 291, the C language function "FindCrescentTop" is called to determine the camera

pixel, or seed pixel 292 representing the highest edge on the top of the crescent. The camera pixel coordinates of the seed pixel are used as the coordinates of a region of interest for determining the subpixel location of the side

5   perspective ball reference point.

One example of grayscale blob analysis and reference point determination implemented in the C language is presented as follows:

```
////////////////////////////////////////////////////////////////////
//
// FindBlobCenter - finds the X,Y center of the pixels that
have a value greater than THRESHOLD in the region (x1,y1) to
(x2,y2)
////////////////////////////////////////////////////////////////////
//
long FindBlobCenter(int x1,int y1,int x2,int y2,
                    double* pX,double* pY)
{
    int x,y;
    long Found = 0;
    long SumX  = 0;
    long SumY  = 0;

    for (x=x1;x<=x2;x++)
    {
        for (y=y1;y<=y2;y++)
        {
            if (Pixel[x][y] > THRESHOLD)
            {
                SumX  += x;
                SumY  += y;
                Found ++;
            }
        }
    }

    if (Found > 0)
    {
        *pX = (double)SumX / (double)Found;
        *pY = (double)SumY / (double)Found;
    }
```

```
        return Found;
    }

    //////////////////////////////////////////////////////////////
    //
5   // FillBallCenter - fills the center of the BGA "donut"
    //////////////////////////////////////////////////////////////
    //
    void FillBallCenter(double CenterX,double CenterY,double
    Diameter)
10  {
        int x,y;
        int x1 = (int)(CenterX - Diamter / 4.0);
        int x2 = (int)(CenterX + Diamter / 4.0);
        int y1 = (int)(CenterY - Diamter / 4.0);
15      int y2 = (int)(CenterY + Diamter / 4.0);

        for (x=x1;x<=x2;x++)
        {
            for (y=y1;y<=y2;y++)
20          {
                Pixel[x][y] = 255;
            }
        }
    }

25  //////////////////////////////////////////////////////////////
    //
    // FindBallCenter - finds the X,Y center of the a BGA ball
    //                  using the grayscale values
    //////////////////////////////////////////////////////////////
30  //
    long FindBallCenter(int x1,int y1,int x2,int y2,
                        double* pX,double* pY,double* pRadius)
    {
        int x,y;
35      long Found = 0;
        long Total = 0;
        long SumX  = 0;
        long SumY  = 0;

40      for (x=x1;x<=x2;x++)
        {
            for (y=y1;y<=y2;y++)
            {
                if (Pixel[x][y] > THRESHOLD)
45              {
                    SumX  += x*Pixel[x][y];
                    SumY  += y*Pixel[x][y];
                    Total += Pixel[x][y];
                    Found ++;
50              }
```

```
            }
        }

        if (Found > 0)
        {
            *pX      = (double)SumX / (double)Total;
            *pY      = (double)SumY / (double)Total;
            *pRadius = sqrt((double)Found / 3.14159279);
        }

        return Found;
    }


    /////////////////////////////////////////////////////////////////////
    //
    // FindCresentTop - finds the X,Y top position of a BGA
    cresent
    /////////////////////////////////////////////////////////////////////
    //
    void FindCresentTop(int CenterX,int CenterY,int Diameter,
                        int* pX,int* pY)
    {
        int x,y,Edge,Max,TopX,TopY;
        int x1   = CenterX - Diamter / 2;
        int x2   = CenterX + Diamter / 2;
        int y1   = CenterY - Diamter / 2;
        int y2   = CenterY;

        *pY = 9999;

        for (x=x1;x<=x2;x++)
        {
            Max = -9999;
            for (y=y1;y<=y2;y++)
            {
                Edge = Pixel[x][y] - Pixel[x][y-1];
                if (Edge > Max)
                {
                    Max  = Edge;
                    TopY = y;
                    TopX = x;
                }
            }
            if (TopY < *pY)
            {
                *pX = TopX;
                *pY = TopY;
            }
        }
    }
    (c) 1997 Scanner Technologies Inc.
```

Figure 8A shows a side perspective image of the

calibration pattern magnified in one dimension. Figure 8A
shows a side perspective image 300 of a reticle calibration
pattern where the space 303 between dot 301 and dot 302 is
magnified, increasing the number of lower value grayscale
5   pixels when compared to a non magnified image.

Figure 8B shows a side perspective image of the balls
on a BGA, magnified in one dimension. In Figure 8B a side
perspective image 310 of two views are shown where the space
313 between ball image 311 and ball image 312 is magnified,
10   increasing the number of lower value grayscale pixels when
compared to a non magnified image. The increased number of
lower grayscale value pixels allows for the successful
application of the subpixel algorithm.

In another embodiment of the invention, the method and
15   apparatus disclosed herein is a method and apparatus for
calibrating the system by placing a pattern of calibration
dots of known spacing and dimensions on the bottom plane of
a calibration reticle and for providing for two side
perspective views of each ball for the three dimensional
20   inspection of parts. From the precision dots the missing
state values of the system are determined allowing for three
dimensional inspection of balls on BGA devices or balls on
wafers or balls on die.

Figure 9 shows an example apparatus for presenting a
25   BGA to the system for inspection. An overhead light
reflective diffuser 5 includes a vacuum cup assembly 6. The

vacuum cup assembly may attach to a BGA part 70 having balls 71 and suspend the BGA part 70 below the overhead light reflective diffuser 5.

Figures 10A and 10B show an example ball on a ball grid array and associated geometry for use with the method of the invention for determining the Z position of a ball with respect to the world coordinates defined during calibration, using two perspective views for each ball. Using parameters determined from the calibration procedure as shown in Figures 2B and 2D to define a world coordinate system for the bottom view and the two side perspective views, comprising world coordinate plane 700 with world coordinate origin 701 and world coordinate axis X 702, Y 703 and Z 704 shown in Figure 10A and Figure 10B, and a pair of images 80 and 90 as shown in Figure 3B, the processor computes a three dimensional location.

Now refer to Figure 10A. The processor locates a point 709 on the world plane 700 determined by a bottom view ray 705 passing through the center 708 of a ball 717. The processor locates a first side perspective view point 711 on the world plane 700 determined by a side view ray 706 intersecting a ball reference point 710 on ball 717 and intersecting the bottom view ray 705 at a virtual point 714. Ray 706 intersects the world plane 700 at an angle 715 determined by the reflection of ray 706 off of the back surface of prism 30. The value of angle 715 was determined

during the calibration procedure. The processor locates a
second side perspective view point 713 on the world plane
700 determined by a side view ray 707 intersecting a ball
reference point 712 on ball 717 and intersecting the bottom
5   view ray 705 at a virtual point 718. Ray 707 intersects the
world plane 700 at an angle 716 determined by the reflection
of ray 707 off of the back surface of prism 34. The value
of angle 716 was determined during the calibration
procedure.

10   Now refer to Figure 10B. The distance L_1 is calculated
by the processor as the distance between world point 709 and
world point 711. The distance L_2 is calculated by the
processor as the distance between world point 713 and world
point 709. The value Z_1 is defined as the distance between
15   world point 714 and 709 and is related to L_1 as follows:

$$\tan \theta_1 = \frac{Z_1}{L_1}$$

$$Z_1 = L_1 \tan \theta_1$$

The value Z_2 is defined as the distance between world point
718 and 709 and is related to L_2 as follows:

$$\tan \theta_2 = \frac{Z_2}{L_2}$$

$$Z_2 = L_2 \tan \theta_2$$

The average of Z_1 and Z_2 are calculated and used as the

value for Z of the ball. This method is more repeatable and accurate than methods that use only one perspective view per ball.

In still another embodiment of the invention, the method and apparatus disclosed herein is a method and apparatus for calibrating the system by placing a pattern of calibration dots of known spacing and dimensions on the bottom plane of a calibration reticle and for providing a single side perspective view for the three dimensional inspection of parts. From the precision dots the missing state values of the system are determined allowing for three dimensional inspection of balls on BGA devices or balls on wafers or balls on die.

Figure 11A shows the apparatus of the invention for system calibration, utilizing a single side perspective view. The method and apparatus for calibration of the bottom view is identical to the method and apparatus described earlier in Figure 2A and 2B for the two side perspective views method. The apparatus for an image of a side perspective view includes a camera 15 with a lens 18 and a calibration reticle 20. The camera 15 is located to receive an image 64 of a side perspective view comprising dots 65, described in conjunction with Figure 11B, and utilizing fixed optical elements 40 and 42. The fixed optical element 40 may be a mirror or prism. The fixed optical element 42 is a nonlinear element that magnifies the image in one

direction. In another embodiment fixed optical element 40
may be this nonlinear element. As will be appreciated by
those skilled in the art additional optical elements may be
incorporated. The camera 15 is connected to a frame grabber

5   board 17 to receive the image 64. The frame grabber board 17
provides an image data output to a processor 13 to perform a
two dimensional inspection as described in conjunction with
Figure 2B. The processor 13 may store an image in memory 14.

Figure 11B shows an example calibration pattern and

10   example images of a calibration pattern acquired by the
system, utilizing a single side perspective view, of the
invention. Figure 11B shows an example image 50 from camera
10 and an example image 64 from camera 15 acquired by the
system. The image 50 showing dots 52 acquired by camera 10

15   includes a bottom view of the dot pattern 22, containing
precision dots 24 of known dimensions and spacing, located
on the bottom surface of the calibration reticle 20. The
image 64 shows a side perspective view of the dot pattern
22, containing precision dots 24 of known dimensions and

20   spacing, located on the bottom surface of the calibration
reticle 20. A side perspective view in image 64 contains
images of dots 65 and is obtained by the reflection of the
image of the calibration reticle dot pattern 22 off of fixed
optical element 40, passing through nonlinear

25   element 42 and into camera 15.

The side perspective calibration is identical to the

method shown in Figure 2C except the fixed optical elements may have different properties.

The determination of the state values for the side perspective view is identical to the method shown in Figure 2D except the fixed optical elements may be different and there is only one side perspective view. The principles and relationships shown in Figure 2E and Figure 2F apply.

In still another embodiment employing a single side perspective view, the invention does not include the nonlinear element 42.

Figure 12A shows the apparatus of the invention for ball inspection utilizing a single side perspective view. The apparatus of the invention includes a part 70 to be inspected. The apparatus further includes a camera 10 with a lens 11, located below the central area of part 70, to receive a bottom image 80, described in conjunction with Figure 12B, of part 70. The camera 10 is connected to a frame grabber board 12 to receive the image 80. The frame grabber board 12 provides an image data output to a processor 13 to perform a two dimensional inspection as described in conjunction with Figure 12B. The processor 13 may store an image in memory 14. The apparatus for an image of a single side perspective view includes a camera 15 with a lens 18. The camera 15 is located to receive an image 94, comprising a single side perspective view, described in conjunction with Figure 12B and utilizing fixed optical

element 40 and nonlinear, fixed optical element 42, to

magnify the side perspective view in one dimension. In

another embodiment of the invention optical element 40 may

be the nonlinear element. The fixed optical element 40 may

5   be a mirror or prism. As will be appreciated by those

skilled in the art additional optical elements may be

incorporated. The camera 15 is connected to a frame grabber

board 17 to receive the image 94. The frame grabber board 17

provides an image data output to a processor 13 to calculate

10   the Z position of the balls, described in conjunction with

Figure 12B. The processor 13 may store an image in memory

14.

Figure 12B shows an example ball grid array and example

images of the ball grid array for three dimensional

15   inspection, utilizing a single side perspective view. Figure

12B shows an example image 80 from camera 10 and an example

image 94 from camera 15 acquired by the system. The image 80

shows the bottom view of the balls 71 located on the bottom

surface of a part 70. The image 94 shows a side perspective

20   view of the balls 71 located on part 70. The side

perspective view in image 94 contains images of balls 95 and

is obtained by the reflection of the image of the part 70

off of fixed optical element 40 and passing through the

nonlinear fixed element 42 into camera 15.

25   In an alternate embodiment of the invention, the system

can be used to inspect other types of electronic parts in

three dimensions, such as gullwing and J lead devices. By utilizing only one camera and adding an additional set of prisms on the reticle 400 these other devices may be inspected. The advantage of being able to inspect different

5   devices with the same system includes savings in cost, and floor space in the factory. Additionally this design allows more flexibility in production planning and resource management.

Figure 13 shows the apparatus of the invention for the

10   three dimensional inspection of ball grid array devices, gullwing devices and J lead devices. The apparatus described in Figure 13 allows the inspection of BGA, gullwing and J lead devices all on the same system. The apparatus includes a part 402 to be inspected located over the central area of

15   a transparent reticle 400 with prisms 401 glued to the top surface to receive side perspective views of part 402. A gullwing and J lead inspection device 21 may be integrated into the ball grid array inspection device. One example embodiment of such a gullwing and J lead inspection device

20   is the "UltraVim" scanner from Scanner Technologies of Minnetonka, Minnesota. The apparatus further includes a camera 10A with a lens 11A, located below the central area of part 402 and reticle 400 to receive a bottom view and side perspective views of part 402. The camera 10A is

25   connected to a frame grabber board 12A to receive an image. The frame grabber board 12A provides an image data output to

a processor 13A to perform a three dimensional inspection of part 402. The processor 13A may store an image in memory 14A. These components comprise the hardware of the gullwing and J lead inspection device 21 and are shared by the ball

5   grid array inspection device as described herein.

The UltraVim is described in United States patent application Serial Number 08/850,473 entitled THREE DIMENSIONAL INSPECTION SYSTEM by Beaty et al., filed May 5, 1997 which is incorporated in its entirely by reference

10   thereto.

Refer now to Figure 14. In still another embodiment of the invention, the system may use three cameras to image directly the bottom view and two side perspective views as shown in Figure 14. Figure 14 shows the apparatus of the

15   invention for a three dimensional inspection of the balls of a BGA. The apparatus of the invention includes a part 70, with balls 71 to be inspected. The apparatus further includes a camera 10 with a lens 11, located below the central area of part 70, to receive a bottom image 80,

20   described in conjunction with Figure 12B, of part 70. The camera 10 is connected to a frame grabber board 12 to receive the image 80. The frame grabber board 12 provides an image data output to a processor 13 to perform a two dimensional inspection as described in conjunction with

25   Figure 12B. The processor 13 may store an image in memory 14. The apparatus for an image of a first side perspective

view includes a camera 15 with a lens 19. The camera 15 is

located to receive an image 94, comprising a single side

perspective view, described in conjunction with Figure 12B

and utilizing fixed optical element 38, to magnify the side

5   perspective view in one dimension. The camera 15 is

connected to a frame grabber board 17 to receive the image

94. The frame grabber board 17 provides an image data

output to a processor 13 to calculate the Z position of the

balls, described in conjunction with Figure 12B. The

10   processor 13 may store an image in memory 14. The apparatus

for an image of a second side perspective view includes a

camera 15 with a lens 19. The camera 15 is located to

receive an image similar to 94, comprising a single side

perspective view, described in conjunction with Figure 12B

15   and utilizing fixed optical element 38, to magnify the side

perspective view in one dimension. The camera 15 is

connected to a frame grabber board 17 to receive the image

similar to 94. The frame grabber board 17 provides an image

data output to a processor 13 to calculate the Z position of

20   the balls, described in conjunction with Figure 12B. The

processor 13 may store an image in memory 14. In another

embodiment, the nonlinear fixed optical element 38 may be

missing. In still another embodiment of the invention, only

one side perspective view may be utilized.

25   In another embodiment of the invention, the method and

apparatus disclosed herein is a method and apparatus using a

single camera for calibrating the system by placing a
pattern of calibration dots of known spacing and size on the
bottom plane of a calibration reticle. From the precision
dots the missing state values of the system are determined
5   allowing for three dimensional inspection of balls on ball
grid array devices, BGA devices or balls on wafers or balls
on die.

Refer now to Figure 15 which shows one example of the
apparatus of the invention configured with a calibration
10   reticle 1020 for use during calibration of the state values
of the system. Calibration reticle 1020 is positioned to be
viewed by camera 1008. Camera 1008 further comprises a lens
1006. Camera 1008 receives a composite image of the
calibration reticle 1020, one portion of the image, through
15   mirror 1002 and an additional portion directly. A frame
grabber 1010 receives image information from the camera 1008
and provides processor 1012 with image information of the
calibration reticle 1020. The image information and other
inspection information may be stored in memory 1014. The
20   apparatus obtains an image 1024 showing a bottom view 1026
containing an image of a precision dot 1030 and a side view
1028 containing an image of precision dot 1032 of the
calibration reticle 1020 shown in Figure 16A. This image
1024 is shown in Figure 16B. To take the image 1024, the
25   apparatus includes a means of illumination 1017, an overhead
light diffuser 1015, the camera 1008, with lens 1006, and

calibration reticle 1020 with a calibration pattern 1021 on the bottom surface of the calibration reticle 1020. A separate optical element 1002 is positioned below the calibration reticle 1020 to provide an additional

5   perspective or side view 1028 containing an image of precision dot 1032 of the calibration reticle 1020.

In one embodiment of the invention, the optical element 1002 may comprise a prism. In another embodiment of the invention, the optical element 1002 may comprise a mirror.

10   As will be appreciated by one skilled in the art, the invention will work with any number of side views. The calibration pattern 1021 on the reticle 1020 comprises precision dots 1022. The camera 1008 is located below the central part of the calibration reticle 1020 to receive an

15   image 1024 described in conjunction with Figures 16A and 16B. In one embodiment of the invention, the camera 1008 comprises an image sensor. The image sensor may be a charged coupled device array. The camera 1008 is connected to a frame grabber board 1010 to receive the image 1024.

20   The frame grabber board 1010 provides an image data output to a processor 1012 to perform a three dimensional calibration as described in conjunction with Figure 16B. The principles and relationships shown in Figures 2E and 2F apply. The processor 1012 may store an image in memory

25   1014.

Now refer to Figures 16A and 16B which show a

calibration reticle 1020 having precision dots 1022. Figure
16B shows a composite image 1024 of the calibration reticle
1020. The bottom view 1026 shows precision dots 1030 with a
first perspective view and a side view 1028 shows precision

5   dots 1030 with a second perspective view. The system
processor processes the composite image 1024 according to
the system of equations described herein with the bottom
view 1026 and side view 1028 providing information for the
solution of the system of equations. The principles and

10   relationships shown in Figure 2E and Figure 2F apply.

In another embodiment of the invention, the method and
apparatus disclosed herein is a method and apparatus using a
single camera for a three dimensional inspection of balls on
ball grid array devices, BGA/CSP devices or balls on wafers

15   or balls on die.

Refer now to Figure 17 which shows the apparatus of the
invention configured with a part 1040 to be inspected by the
system. The apparatus obtains an image 1044 showing a
bottom view 1046 containing an image of a ball 1050 and a

20   side view 1048 containing an image of a ball 1052 of the
part 1040. To take the image 1044, the apparatus includes a
means of illumination 1017 which may be a ring light, camera
1008 with a lens 1006 and a part 1040 with a ball 1042 on
the bottom surface. In one embodiment of the invention, the

25   means of illumination 1017 lights the bottom surface of the
part 1040 to allow imaging the perimeter of the part 1040.

In another embodiment of the invention, overhead diffuser 1015 provides illumination for imaging of the perimeter of the part 1040.

A separate optical element 1002 is positioned below the bottom plane of part 1040 to provide an additional perspective or side view 1048 of the part 1040 containing an image of the ball 1052 of the part 1040. In one embodiment of the invention, the optical element 1002 may comprise a prism. In another embodiment of the invention, the optical element 1002 may comprise a mirror. As will be appreciated by one skilled in the art, the invention will work with any number of side views. The camera 1008 is located below the central part of the part 1040 to receive an image 1044 described in conjunction with Figures 18A and 18B. In one embodiment of the invention, the camera 1008 comprises an image sensor. The image sensor may be a charged coupled device array. The camera 1008 is connected to a frame grabber board 1010 to receive the image 1044. The frame grabber board 1010 provides an image data output to a processor 1012 to perform a three dimensional inspection of the part 1040 as described in conjunction with Figures 18A and 18B. The principles and relationships shown in Figures 6A and Figure 6B apply. The processor 1012 may store an image in memory 1014.

Now refer to Figures 18A and 18B which show a ball grid array 1040 having balls 1042. Figure 18B shows a composite

image 1044 of the ball grid array 1040. The bottom view

1046 shows ball 1050 with a first perspective view and a

side view 1048 shows ball 1050 with crescent shape 1052 with

a second perspective view. The system processor processes

5   the composite image 1044 according to the system of

equations described herein with the bottom view 1046 and

side view 1048 providing information for the solution of the

system of equations. The principles and relationships shown

in Figures 6A and 6B apply.

10   The invention has been described herein in considerable

detail in order to comply with the Patent Statutes and to

provide those skilled in the art with the information needed

to apply the novel principles and to construct and use such

specialized components as are required. However, it is to

15   be understood that the invention can be carried out by

specifically different equipment and devices, and that

various modifications, both as to the equipment details and

operating procedures, can be accomplished without departing

from the scope of the invention itself.

20   What is claimed is: